

Exploring scaling issues by using NASA Cold Land Processes Experiment (CLPX-1, IOP3) radiometric data

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Abstract— The NASA Cold-land Processes Field Experiment-1 (CLPX-1) involved several instruments in order to acquire data at different spatial resolutions. Indeed, one of the main tasks of CLPX-1 was to explore scaling issues associated with microwave remote sensing of snowpacks. To achieve this task, microwave brightness temperatures collected at 18.7, 36.5, and 89 GHz at LSOS test site by means of the University of Tokyo's Ground Based Microwave Radiometer-7 (GBMR-7) were compared with brightness temperatures recorded by the NOAA Polarimetric Scanning Radiometer (PSR/A) and by SSM/I and AMSR-E radiometers. Differences between different scales observations were observed and they may be due to the topography of the terrain and to observed footprints. In the case of satellite and airborne data, indeed, it is necessary to consider the heterogeneity of the terrain and the presence of trees inside the observed scene becomes a very important factor. Also when comparing data acquired only by the two satellites, differences were found. Different acquisition times and footprint positions, together with different calibration and validation procedures, can be responsible for the observed differences.

Keywords- Snow, Microwave remote sensing, scaling issue

I. INTRODUCTION

One of the major tasks of passive microwave remote sensing of snow is the retrieval of snow parameters for hydrological, meteorological and climatological applications as well as for discharge forecasting for hydropower production. The northern hemisphere land surface is covered by snow in midwinter for more than 60 %, and over 30% of Earth's total land surface has seasonal snow [1]. Snow covers are very important in the Earth's energy cycle, and through their effects on land surface albedo, the net radiation balance, and boundary layer stability, strongly affect weather patterns over large areas.

Several algorithms for the retrieval of snow parameters such as snow depth and snow water equivalent (SWE) have been developed (i.e. [2]-[8]). These algorithms are generally applied to microwave satellite data (such as SSM/I brightness

temperatures) and retrieved parameters are compared with ground based field measurements. Parameters derived on a large scale, such as that one of the SSM/I and AMSR-E, are, therefore, compared with snow parameters measured on a local scale. In the case of satellite data, it must be also considered that collected data are influenced by the presence of trees inside the observed scene. For this reason, it is important to analyse the behaviour of the brightness temperatures when scaling from small to large observation scales.

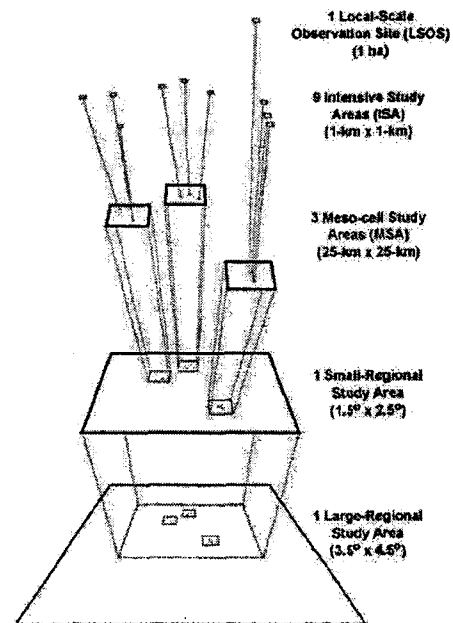


Figure 1. Schematic diagram of the nested study areas for the Cold Land Processes Field Experiment

One of the main tasks of the CLPX/1 was to explore scaling issues related to the microwave remote sensing of snow. For

this reason, intensive ground, airborne, and spaceborne observations were collected in Colorado, central Rocky Mountain of the western United States, during February and late March of both 2002 and 2003. for a total of four week-long Intensive Observation Periods (IOPs). A set of nested study areas, ranging from 1 ha to 160,000 km² was considered to collect data over different spatial scales.

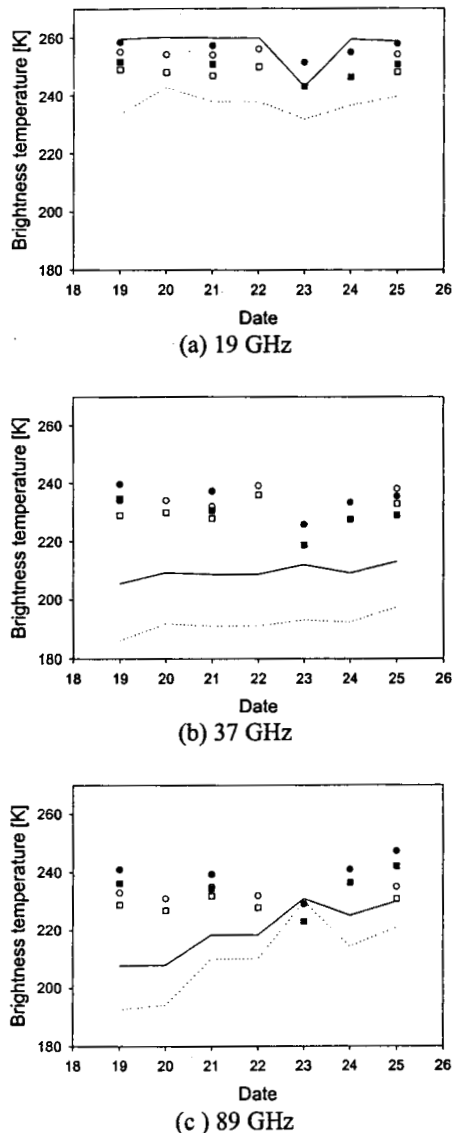


Figure 2. Comparison between SSM/I, AMSR-E and GBMR-7 radiometer at 19 (a), 37 (b) and 89 (c) GHz for different dates of the IOP3 period. AMSR-E = squares, SSM/I = circles (black = V pol., white = H pol.), GBMR-7 (lines, cont = V pol., dot = H pol.)

In this study, brightness temperatures acquired by means of the University of Tokyo's Ground Based Microwave Radiometer-7 (GBMR-7), the NOAA Polarimetric Scanning Radiometer (PSR/A), the SSM/I and AMSR-E radiometers during the third Intensive Observation Period (IOP3, dry snow, February 19 - 25, 2003) at the Local Scale Observation

Site (LSOS) and Rabbit Ears Meso-cell study are have been analyzed and compared.

II. THE TEST SITES AND RADIOMETRIC ACQUISITION SYSTEMS

Figure 1. shows the schematic diagram of the study areas for the CLPX-1. The smallest one is the Local Scale Observation Site (LSOS), consisting of a small (0.8-ha) clearing surrounded by trees and located within the CLPX Fraser Intensive Study Area (ISA), near the Fraser Experimental Forest Headquarters Facility, Colorado (105°54'40" W, 39°50'49"N, 2780 m a.s.l.). Inside each Meso-cell Study Areas (MSA, 25x25 Km²), three Intensive Study Areas (ISA's, 1x1 Km²) were considered, for a total of nine ISA's. Ground radiometric data were daily collected in the small clearing at the LSOS by means of the University of Tokyo's Ground based Radiometer (GBMR-7) [9]-[10]. Brightness temperatures were collected at 18.7, 36.5 and 89 GHz at different observation and azimuth angles, including the observation angle of 55°. A main characteristic of the GBMR-7 is that it could operate within the temperature range of -30 /+40 °C because receiver electronics, mirrors and lenses were encapsulated in a thermal stabilized box. Microwave data were collected over the three MSA's also by means of the NOAA Polarimetric Scanning Radiometer (PSR/A), an airborne multiband conical-scanned imaging radiometer system. PSR/A includes a single scanhead that provides imagery at most of the AMSR-E imaging bands. The PSR/A data were acquired with an observation angle of 53°. Microwave satellite data, acquired by means of the SSM/I radiometer flying on the DMSP F13 series satellite and by means of the Aqua AMSR-E radiometer were also used.

III. EXPERIMENTAL DATA AND DISCUSSION

Microwave satellite data were preliminary compared with ground based data acquired by the GBMR-7. The temporal and spatial coverage of satellite data was guaranteed by using either ascending or descending orbits data. In Figure 2. both ascending and descending data recorded by SSM/I and AMSR-E are reported, together with data collected on ground by the GBMR-7. More in detail, Figure 2. shows the comparison between SSM/I, AMSR-E and GBMR-7 radiometer at 19 (a), 37 (b) and 89 (c) GHz. In the Figure, AMSR-E data are represented by squares where SSM/I data by circles (black symbols are used for the V pol and white ones for the H pol.). GBMR-7 vertical brightness temperatures are represented by continuous lines where horizontal ones are represented by dotted lines. It comes out that at 19 GHz satellite and ground based microwave brightness temperatures are comparable, even if the difference between vertical and horizontal polarization is high for ground based data. At 37 and 89 GHz, brightness temperatures recorded by satellites are generally higher than those recorded by the GBMR-7. Also in this case the difference between vertical and horizontal polarizations for ground-based data is higher than that obtained with satellite data. Several factors can be the cause of the discrepancies between ground and satellite brightness temperatures. Firstly, we have to consider that we are comparing data acquired at

different hours. Ground data were generally collected during the morning; SSM/I data were acquired around 1:00 for the ascending pass and around 13:00 for the descending one where AMSR-E data were acquired around 20:00 for the ascending orbit and around 9:00 for the descending one. Air and snow temperatures were analyzed for the different hours by using the data collected by automatic meteorological stations located at LSOS test sites. The maximum difference was around 7 K. Another factor that must be also considered is the size of the footprint for the ground-based and satellite-mounted radiometers. In the first case the footprint is relatively small and the antenna instrument is observing the only snow -pack overlying the soil. In the case of satellite, the footprint is 25x25 Km² and the scene observed by the radiometer includes also trees, strongly influencing the observed brightness temperature. The percentage of forest coverage for the MSA (representing one single pixel in the case of AMSR-E and SSM/I data) including the LSOS was calculated by re-sampling (25 Km) the NDVI derived from the MODIS instrument and it was $f_{for} = 36.7\%$.

Differences between the two satellite-mounted radiometers data were observed and it can be due to the different footprint positions as well as to different calibration and validation procedures. Satellite and ground based data were also compared with PSR/A brightness temperatures acquired over the LSOS on February 23 and February 25. The footprint dimension ranged between 88 and 209 meters for the 37 and 89 GHz channels and between 184 and 708 meters for the 19 GHz channel. Figure 3. shows brightness temperatures at LSOS recorded by different instruments at 18.7, 37 and 89 GHz. In the Figure acquisition hours for each instrument are also reported. It is possible to see that, at 37 and 89 GHz a remarkable difference exists between ground-based and airborne/spaceborne data. This difference reduces at 18.7 GHz. In general, differences between ground-based and airborne data are higher than those ones between ground-based and satellite data. This can be explained by considering that the fraction of forest cover is higher than that one obtained for the satellite data. As already done in the satellite case, the NDVI derived from the MODIS instrument was used to calculate the forest cover fraction of the observed test sites. In particular, the cover fraction of the PSR data pixel (250 m resolution) including the LSOS resulted to be 67.2 %. If we divide the observed scene into forested and un-forested areas and if we disregard the atmospheric effects, then we can approximate the scene brightness temperature by

$$T_b(\theta) = f_{for} T_{b,for}(\theta) + (1 - f_{for}) T_{b,snow}(\theta) \quad (1)$$

where f_{for} is the forest cover fraction. If we consider an average value of 275 K for trees temperatures ($T_{trees} = 275$ K), which is in good agreement with measurements conducted on trees during the CLPX experiment, we can estimate the brightness

	February 23				February 25				
Freq. (GHz)	PSR/GBMR-7 [K]		SSM/I [K]		PSR/GBMR-7 [K]		SSM/I [K]		
NDVI=0									
10	253.4	243.0			260.9	254			
19	249.2/245	236/230	258.1	248.2	259/257	255.3/241	256.3	242	
21	246.4	232.8			258.7	255.3			
37	251/220	216.2/219	250.5	243.1	252/210	249.3/201	246.8	237	
85	Na/219	Na/210	243.3	237.9	237.3/227	231.1/222	238	230.5	
NDVI=100									
10	255.3	252.2			261.9	245.5			
19	252.7	250.6	258.4	246.6	260.4	259.1	258.1	247	
21	251.7	249.7			261	259.5			
37	250.51	249.9	250.5	242.8	258.2	256.5	250.8	241	
85	na	Na	245.4	240.9	243.8	239	241.4	233.9	

TABLE I. BRIGHTNESS TEMPERATURES ACQUIRED ON FEBRUARY 23 AND FEBRUARY 25 BY THE GBMR-7, PSR AND SSM/I AT DIFFERENT FREQUENCIES.

temperatures measured by the PSR and spaceborne radiometers by using Eq. 1. If we consider $f_{for-PSR} = 0.672$ and $f_{for-SATELLITE} = 0.367$ we have that the brightness temperature at vertical polarization at 37 GHz for the PSR is $T_{PSR} = 254$ K and that one for the satellites is $T_{SATELLITE} = 233$ K. At 89 GHz we have $T_{PSR} = 260$ K and that one for the satellites is $T_{SATELLITE} = 251$ K. Obtained results are in good agreement with measured brightness temperatures. As stated, the difference between ground-based and airborne/spaceborne data is small at 18.7 GHz. This could be due to the higher penetration depth of the electromagnetic radiation. Brightness temperatures computed by using the Eq. 1 at 18.7 GHz at vertical polarization are the following: $T_{PSR} = 270$ K and $T_{SATELLITE} = 260$ K. Satisfactory results are obtained also in the horizontal polarization case. Polarization effects were also observed. At all frequencies, the difference between vertical and horizontal brightness temperatures is maximum for the GBMR-7 data, it reduces for PSR data (reaching its minimum) to increase again for satellite data. It is known ([11],[12]) that the presence of ice crystals in dry snow tends to separate the vertical and horizontal polarizations because of the volumetric scattering effects (GBMR-7 data). The difference between two polarizations increases as the fractional forest coverage decreases.

Brightness temperatures in areas close to the LSOS test site having either NDVI = 0 % and NDVI = 100 % were also analysed. TABLE I. shows brightness temperatures acquired on February 23 and February 25 by the GBMR-7, PSR and SSM/I at different frequencies for both values of NDVI. For NDVI = 0, differences between PSR and GBMR-7 data are small on February 23. On February 25, these differences are small at 19 GHz, but at 37 GHz they are of the order of 40 K. This phenomenon needs further studies and it will be investigated in future studies. Brightness temperatures collected in those areas with NDVI = 100 % are, as expected, very similar at all frequencies with data collected by the PSR similar to those ones collected by the SSM/I.

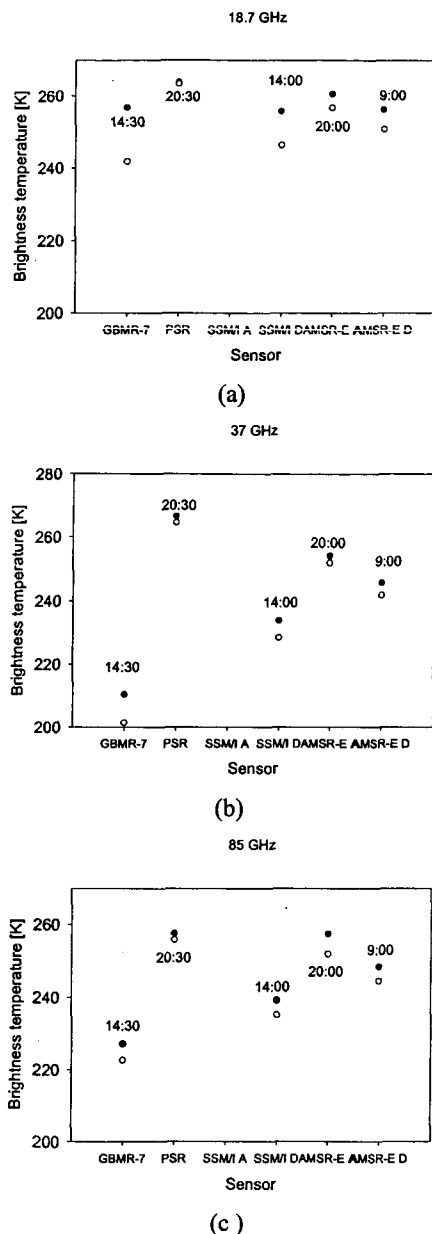


Figure 3. Brightness temperatures recorded on February 25, 2003 by different instruments extracted from the pixels containing the LSOS test site at 18.7 (a) , 37 (b) and 89 (c) GHz.

IV. CONCLUSIONS

Microwave brightness temperatures collected at 18.7, 36.5, and 89 GHz at LSOS test site by means of the University of Tokyo's Ground Based Microwave Radiometer-7 (GBMR-7) were compared with brightness temperatures recorded by the NOAA Polarimetric Scanning Radiometer (PSR/A) and by SSM/I and AMSR-E radiometers. Differences were observed at different scales observations. Beside the topography of the

terrain, the observed footprints were the cause of the observed differences. The effect of trees inside the footprints was analyzed and modeled using the forest fractional coverage derived from MODIS data. Moreover, it was also observed that the difference between vertical and horizontal polarization was maximum for ground based measurements, it reduces to its minimum for PSR data (fractional forest coverage high), and then it increases again for satellite. Note that also when comparing data acquired only by the two satellites, differences were found. Different acquisition times and footprint positions, together with different calibration and validation procedures, can be responsible for the observed differences.

Scaling related to microwave remote sensing of snow will proceed with data at our disposal by using data collected during wet snow period. In the future, the application of retrieval algorithms at different scales, the comparison of obtained results with ground measurements of snow distributed over the area of interest will be carried out.

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